Idaho National Engineering and Environmental Laboratory

One-Dimensional Solute Transport in Variably Saturated Soil Using a Geocentrifuge Apparatus

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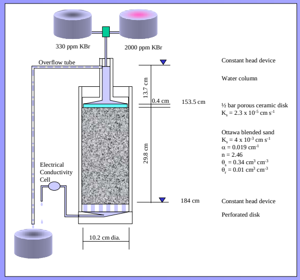
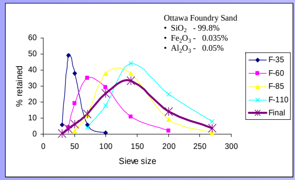
Abstract

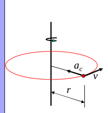
Solute transport data in variably saturated porous media have been difficult to obtain due to long experimental times required to conduct such experiments. Larger length scales of tens of cm require months of experimental time. These long experimental times increase the likelihood of undesirable secondary effects, such as biofouling and instrumentation failure compromising the experimental results. The geocentrifuge offers a potential experimental technique to shorten experimental time scales and thereby overcome these limitations.

One-dimensional solute transport experiments (10-cm diameter by 30-cm in length) were conducted using the INEEL 2-m geocentrifuge. Potassium bromide was used as a tracer through Ottawa quartz sand to develop geocentrifuge experimental methodologies and to test a modified numerical tool to design and analyze the results from these experiments. Breakthrough curves were determined through in-flight monitoring of the electrical conductivity of the outflow at 10- and 20- "g"s. Solute transport velocity is proportional to the applied centrifugal acceleration. Breakthrough curves presented in this paper were obtained in less than 2 hours. The time it took to obtain these experimental results is inversely proportional to the applied centrifugal acceleration and is a fraction of the time that it would have taken in using traditional laboratory methods. A modified version of HYDRUS-1D was used to evaluate the solute breakthrough curves. The success of these geocentrifuge experiments suggests that the geocentrifuge technique is a practical and faster experimental methodology to complete tracer experiments in variable saturated media.

Experimental Setup







$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{\left(rpm * \frac{2\pi r}{rotation} * \frac{1 \min}{60 \sec}\right)^2}{r}$$

$$a_c = \omega^2 r$$

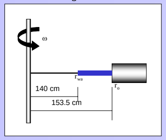
INEEL Geocentrifuge

Experimental Methodology

To conduct an experiment:
• a sand packed column, monitoring instrumentation, input solutions, and a waste tank were loaded on the 2-m geocentrifuge platform
• a background solution of 330 ppm KBr solution was used to saturate the blended sand
• the centrifuge was started after the 330 ppm solution filled the constant head reservoir
• centrifugal forces were established on the experimental package by setting the rpm
• after steady readings on the tensiometers and the electrical conductivity meter were established, the input solution was switched to the 2000 ppm solution to begin the tracer experiment
• approximately two pore volumes of the 2000 ppm solution were passed through the column before the input solution was switched back to the original 330 ppm KBr solution.
• at the of the column, the outflow electrical conductivity was monitor and the experiment was completed when the electrical conductivity approached the initial background solution.

Upper Boundary Calculations

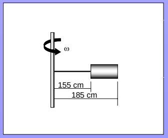
$$H = \frac{\omega^2}{2g}\left(r_o^2 - r_{wa}^2\right)$$

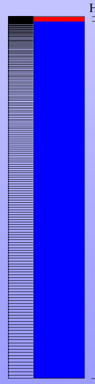


	10 'g'	20 'g'
H_{top} (cm)	118	231
H_{bot} (cm)	0	0
ω (s^{-1})	7.6	10.7
Tracer injection time (s)	2160	1575

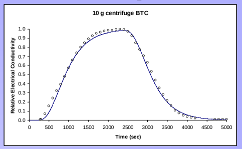
Modeling Methodology

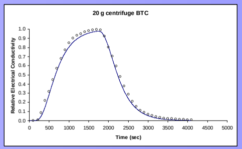
A modified version of HYDRUS 1D (Simunek et al, this session) was used to analyze the experimental results. The upper and lower boundary conditions were set as constant head conditions. The hydraulic conductivity of the ceramic was optimized to predict the solute velocity whereas the dispersivity was optimized for the blended sand. All other parameters were determined independently from laboratory measurements (see Experimental Setup) and data collected when conducting the experiment (see Experimental Methodology).





Experimental Results





$$v = \frac{q}{\theta} = -\frac{K(\psi)}{\theta}\left(\frac{dh}{dr} - \frac{\omega^2 r}{g}\right)$$

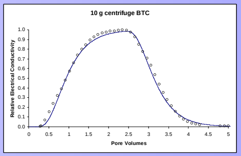
$$if \quad \frac{dh}{dr} \ll \frac{\omega^2 r}{g}$$

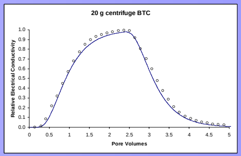
then

$$v \propto \frac{\omega^2 r}{g} \equiv N$$

$$t \propto N$$

Modeling Results





	K_s (cm s^{-1})	Dispersivity (cm)
Experimental	2.3×10^{-3}	-
Model 10g	2.0×10^{-3}	3.78
Model 20g	1.4×10^{-3}	4.65

Conclusions

The modified version of HYDRUS 1D appears to be an appropriate to design geocentrifuge flow and transport experiments.

Experimental data from geocentrifuge experiments can be analyzed using HYDRUS's parameter optimization code.

Due to enhanced velocities in geocentrifuge experiments, solute breakthrough curves are compressed by a factor of approximately N. This result suggests the need for:

- inflight measurement/sampling of BTC
- accurate measurements of the boundary conditions

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